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A New Dynamic Code Assignment Algorithm for Joint CDMA and SDMA system

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***Abstract-* This article describes an optimal dynamic code assignment algorithm, which can be used to maximize the total number of users in combined C-SDMA system with minimum required Quality of Service (QoS) and limited number of codes. Here, a single cell adopts combined C-SDMA system as air-interface, and accommodate any number of users distributed randomly within it. The probability of blocking is calculated to evaluate the system performance for different number of users and available codes. Results show that the proposed algorithm improves the system performance significantly compared to the existing algorithms. Finally, this algorithm enhances system capacity with limited resources.**

Keywords: Wireless CDMA, SDMA, Code assignement, code reuse ratio, Smart antenna.

I. INTRODUCTION

Antenna systems play an important role in any wireless communication system. In which, the system performance can be improved by improving the antenna transmission and reception of different signals. There have been several efforts to improve the performance of mobile systems using different types of antenna systems. Cell splitting, sectoring, repeaters and a microcell zone are some of the developed techniques to enhance the system performance, where Omni directional and sectored antennas were used [1]. Recently, Smart antenna system has been developed with new attractive features. Unlike the Omni directional antenna, in smart antenna system the radiated power is controlled in such a way, the base station antenna radiating a narrow beam with a maximum antenna gain toward the desired user, while the Multiple Access Interference (MAI) from the other interferer users can be reduced or even cancelled by nulling the antenna gain in the direction of those interferers as shown in Figure 1. Therefore, the system performance can be improved [2, 3].

The real radiation patterns of a smart antenna system for three users are depicted in Figure 2. It can be seen from hat single narrow beam is generated and radiated toward ach mobile user with maximum gain and null can be receded to the other interferer users (see Figure 2, (a)). However, the generated beams can be narrower by increasing the number of antenna elements; thus, more degree of orthogonality can be maintained [3, 5]. Due to the high mobility of the mobile users, interferers cannot be completely nulled: So, MAI interference due to the side lobes affects the detection performance of the desired user as shown in Figure 2 (b).

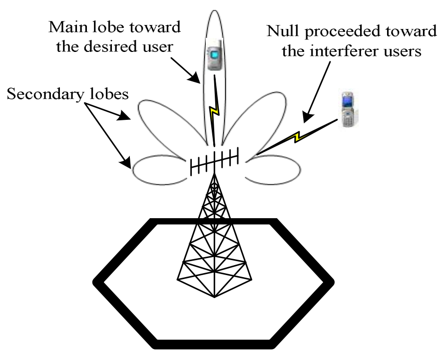

Figure 1. CDMA with smart antenna system

In conventional CDMA systems, pre-assigned code signatures are allocated to different users in order to differentiate them. However, replacing the omnidirectional antenna by a smart antenna system allows those codes to be reassigned to different users if they are spatially separated. Referring to Figure 2 (a), it is clear that one spreading code can be utilized by the three users due to their perfect orthogonal. This new system is called combined CDMA/SDMA. The process of reallocating the spreading codes in the combined system depends on the user locations specified by their Angle of Arrival (AOA). This means that the same code can be utilized by two or more users whose spatial correlation is less than a certain predetermined value.

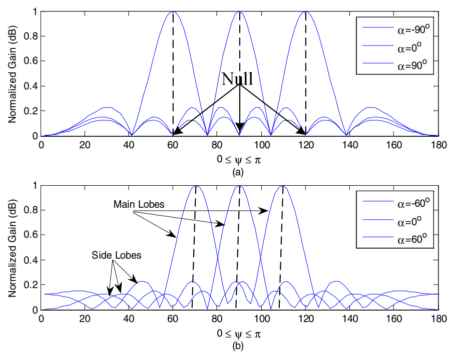

Figure 2. Smart Antenna Radiation Pattern: (a) Orthogonal Patterns with Null interference, (b) Non orthogonal Patterns with side lobe Interference

Furthermore, since spreading codes are reused and due to the challenge in code assignment for the proposed combined system, it is vital to reuse those codes in more efficient manner to enable a high number of users to be accommodated by those limited number of good spreading codes. Channel allocation has been considered in many papers [4-6], but in most of the proposed algorithms the user distribution is considered fixed, and the number of users that are able to reuse the same code is fixed. Since the total number of available conventional channels (spreading codes) is fixed, it follows that the total number of users is also fixed. A more realistic practical assumption is to assume that users are randomly distributed within the serving cell and that the total number of users is variable according to the maximum allowed MAI interference. Additionally, in order to increase the system capacity, one way is to maximize the number of users those are able to use the same code, which can be obtained by maximizing the reuse efficiency of the spreading codes. In dynamic code allocation algorithm spreading codes can be allocated dynamically, which is when the amount of interference exceeds certain predetermined value, the spreading code can be changed. In the proposed algorithm complete interference between two or more users can be avoided, thus more users can be accommodated using a fixed and small number of spreading codes.

II. SMART ANTENNA ATTRACTIVE FEATURES

Smart antenna is a promising technique to improve the system performance of a Mobile Cellular System. This improvement can be achieved by several ways [8, 9]:

- *Increase Base Station Range*: smart antenna focuses the
- radiated beams with maximum gain in one direction; the radiated beam can reach further distance due to its high gain. This means the coverage area of the cell is increased and hence more users are able to use this base station to communicate.
- *Reducing the Multiple Access Interference (MAI):* Smart antennas transmit and receives from each user through its own dedicated narrow beam. Thus user is only affected by other users located within the narrow beam coverage area.
  - *Increase the capacity*: The system capacity can be increased using smart antennas in two ways o Increasing Channel Reuse: Since the total MAI interference is decreased, then for the same minimum quality constraint, the channel reuse pattern can be increased.
  - *Intra-Cell Channel Reuse*: Since all users within the cell are spatially separated, the same channel can be reused within the same cell.

Power Control: the capability of smart antennas to focus the transmitted beams into specific direction reduces the power consumption. In other words, only the needed power is radiated in a right direction during the downlink transmission. On the other hand, in uplink transmission, mobile station can transmit signals with low power, and the BS antenna is able to detect this low power signal because the amount of interference on this signal is very small. Thus, mobile station battery life can be improved which is a very important factor on the cellular mobile communication.

III. SYSTEM MODEL

Consider that there are K users accommodated by the combined CDMA-SDMA system, and let the total number of available codes is equal to L, those codes having a perfect correlation properties, where, $(L \le K)$, thus, if $L=K$, then each code is utilized by one user, but on the other hand, if $L<K$, then, each code is utilized by more than one user. The total number of users can be expressed as

$$K = \sum_{l=1}^{L} G_l \tag{1}$$

Where, G_l is the total number of users using the l-th CDMA channel (spreading code) and those users are considered as one SDMA group.

Under the assumption of perfect synchronization, and assuming that the desired vk-th user (k-th user of the v-th SDMA group, $v \in \{1, 2, \Lambda, L\}, k \in \{1_l, 2_l, \Lambda, G_l\}$) is transmitting signals at AOA of 90^{o} with respect to the base station, and the other (K-1) interferers are transmitting their signal to the base station at different AOA's with a phase shift of α with respect to the desired user AOA. The received signal to the base station at AOA of the desired user $(\psi_{k,v})$ can be expressed as:

$$r(t, \psi_{k,v}) = \sum_{l=1}^{L} \sum_{m=1}^{G_l} A_{m,l} C_l(t) V_{k,v}(\psi_{m,l}) b_{m,l} + n_{k,v}(t) \tag{2}$$

where $A_{m,l}$ $b_{m,l}$, $C_l(t)$, and $n_{k,v}(t)$ are the signal amplitude, transmitted ± 1 BPSK bits, signature sequence and Gaussian Noise (AWGN) respectively. $V_{m,l}(\psi_{k,v})$ represents the radiation pattern gain received by the m,l-th user at AOA of the desired k,v-th user, and it is given by [7]

$$V_{m,l}(\psi_{k,v}) = \frac{1}{N_e} \left| \frac{\sin N_e(\pi d \cos\psi_{k,v} + \alpha/2)}{\sin(\pi d \cos\psi_{k,v} + \alpha/2)} \right| \tag{3}$$

Note that, Equation (3) gives a unity value for the desired user on his own direction. N_e is the total number of antenna elements, d is the inter-element spacing constant and it is given as 0.5 for half wavelength spacing, and α is the phase shift between different users.

IV. SOURCE OF INTERFERENCE

From Equation (2) the output of the respective v-th correlator is given by

$$
\begin{aligned}
y_{k,v}(t,\psi) &= A_{k,v} b_{k,v} + \sum_{\substack{m=1 \\ m \neq k}}^{G_v} A_{m,v} V_{k,v}(\psi_{m,v}) b_{m,v} \\
&\quad + \sum_{\substack{l=1 \\ l \neq v}}^{L} \sum_{m=1}^{Gi} A_{m,l} V_{k,v}(\psi_{m,l}) \rho_{v,l} b_{m,l} + n_{k,v}(t) \qquad (4) \\
&= S + MAI^{h} + MAI^{L-h} + \eta
\end{aligned}
$$

where, MAI^h and MAI^{L-h} are the multiple access interference generated by the home group and the other (*L-h*) groups respectively. S and η, represents the desired signal and the AWGN noise respectively. And, $\rho_{v,l}$ represents the normalized cross correlation between the *v*-th and *l*-th users code sequences, and it is given by:

$$
\rho_{v,l} = \int_{(n-1)T_b}^{nT_b} C_v(t) C_l(t)\, dt \qquad (5)
$$

It can be seen from Equation (4) that, users are affected by the MAI interference due to side lobe interference as in MAI^h and due to both side lobe and cross correlations as in MAI^{L-h}. However, the home group interference is more sever than the interference from other groups due to the joint spatial and code signatures, while within the same group only the spatial signature able to differentiate the users.

So, in order to ensure a minimum quality, users are allowed to reuse the one spreading code only if they satisfy a certain condition, in which, the spatial correlation between different users does not exceed certain predetermined value. Otherwise, new code will be assigned to the new user or user will be blocked in case of all codes are already utilized by other users.

V. Dynamic Code Assignment Algorithm (DCAA)

In this section, dynamic code allocation algorithm is proposed for combined CDMA-SDMA system. Consider that there are *K* users accommodated by the combined system, and let the total number of available semi-orthogonal codes is equal to *L*. The algorithm is illustrated in Figure 3, and it can be summarized as the following:

At the beginning, the cell sector is empty of users, i.e., $K = 0$. Now assume that the first user started to be served by this cell, then $K=1$, and since we have $L > 1$ available codes, so in this case $K<L$ and hence any arbitrary code (c_i) is assigned to this new user, where $c_i \in C_L$, and $C_L = \{c_1, c_2, \cdots, c_i, \cdots, c_L\}$.

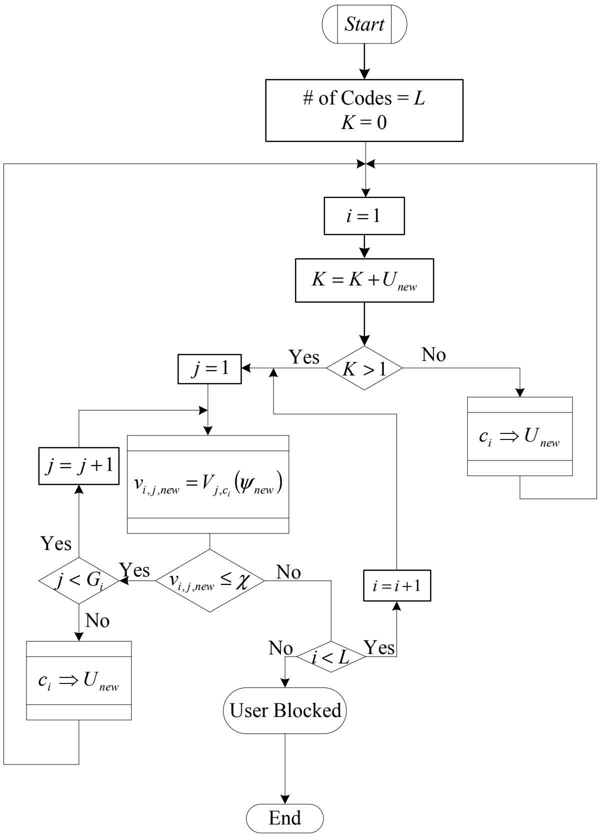

Figure 3. Dynamic Code Assignment Algorithm (DCAA)

Next, assume that one more user is going to join the same cell, i.e., $K = 2$. Then the same code of the previous user (first user) (c_i) can be assigned again to the new user if the Antenna Gain (AG) of the existing user on the direction of the new user is less than or equal to certain threshold, otherwise, new spreading code (c_{i+1}) is assigned to the new user. In mathematical representation, we can write

$$
\begin{array}{ll}
c_i \Rightarrow U_{new} & V_{i,c_j}(\psi_{new}) \leq \chi \\
c_{i+1} \Rightarrow U_{new} & else
\end{array} \qquad (6)
$$

where, χ is a certain threshold value to ensure having a certain minimum quality.

The same principles are applied to the followed coming users, in which, for each a new user the condition in Equation (6) must be satisfied for all users using the same spreading code (SDMA group), thus, if the condition is satisfied for all users within one group, the same code can be assigned to the new user, otherwise, the algorithm, starting to test for the next SDMA group. This process is repeated until satisfying the threshold condition for certain spreading code. If the condition doesn't satisfied for all codes, the user will be blocked.

The advantages of this assignment strategy are that the complexity is very less, since the calculations of the AG is done successively until one SDMA group satisfy the threshold condition and accept the new user. So, the AG calculation for the followed groups is not necessary.

VI. BLOCKING PROBABILITY

The blocking probability is calculated here as the probability of having a new user located at a certain location in which, all of the available codes are already utilized by other users and at the same time, the spatial correlation between the new user and at least one user from each SDMA group exceeds the certain predetermined value.

Due to the randomization of the user's distribution, it is not easy to get a mathematical model to calculate the probability of blocking. For this reason, the blocking probability is calculated here in terms of simulation for different numbers of users.

VII. DYNAMIC HARD HAND OFF (DHHO)

In case when the mobility of mobile users is high, two users may interfere with each other if they use the same spreading code and are moving towards each other. In such a case, one of the users must update his spreading code; this technique may be referred to as hand off. But, unlike the soft hand off in CDMA system, a Dynamic Hard Hand Off (DHHO) is proposed to overcome the above mentioned problem. The process of DHHO is similar to looking for suitable spreading code for a new user as discussed in section IV. However, in order to avoid the user from getting blocked when there are no suitable spreading codes left, we propose that if one or both users are moving with high speed towards each other (such as on the high way), the base station assigns a temporary reserve code to the higher speed user, and then the user releases this code and use his previous one when the spatial separation between these users satisfy the threshold again.

On the other hand, if the movement of one or both users is slow, then the reserved spreading code is un-efficient in this case. That is because; this spreading code will be occupied for a long time by one of the users until both users satisfy the threshold again and hence, other users will be prevented from using this code. Therefore, in this case one of the users requires to update his spreading code by a new code utilized by other users, those are spatially orthogonal to this user as discussed in previous section. The worst case can be happened if the base station fails to find a suitable spreading code for any of them. In this case the base station will optimize and refresh all the pre-assigned codes for all users in order to provide the best possible code assignment.

VIII. NUMERICAL RESULTS

In this section the proposed algorithm will be used to allocate different number of codes to different number of users. Unlimited $\left(L=\infty\right)$ and limited number of available spreading codes is considered to evaluate the proposed DCAA.

1. Unlimited Number of Spreading codes

Here we consider the distribution of mobile users as uniform and random distributions. By which, in uniform distribution users AOAs are fixed with a similar separation distances between successive users. While in random distribution, users are located with random and independent AOAs. 100 users with different AOAs are considered with unlimited spreading codes. For any two users to reuse the same code the minimum separation distance between them (threshold) in terms of maximum spatial correlation is considered as 0.1.

In Fig. 4. users are considered to be uniformly distributed with phase shift of 90° AOA of the desired user, the maximum and minimum shifts are 120° and -120° respectively and the angular distance between successive users is 2.4242°. In Fig. 5 users are randomly distributed within the cell area.

It could be seen from Fig. 4 that only 20 spreading codes are needed in order to accommodate 100 users simultaneously.

On the other hand, in Fig. 5, the average number of required spreading codes is 33.32 ≈ 34 for the same 100 users. However, the user distribution plays an important role in which for the uniform distribution the reuse ratio is much greater than that of the random distribution. This is because in uniform distribution the probability of having groups of users spatially orthogonal or semi-orthogonal apart is higher than that of random distribution case.

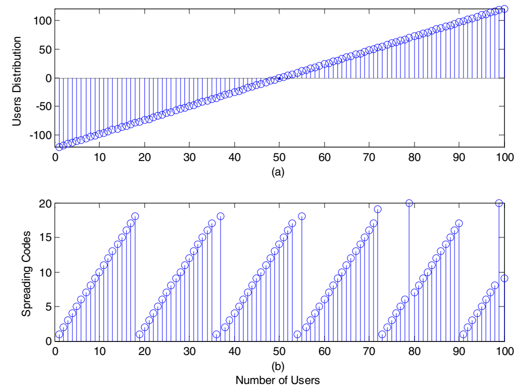

Figure 4. (a) User Uniform Distribution, (b) Dynamic Code Assignment

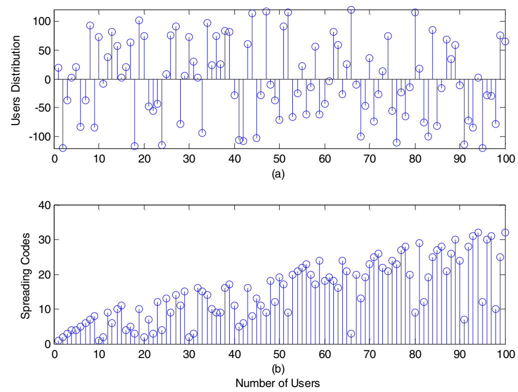

Figure 5. (a) User random Distribution, (b) Dynamic Code Assignment

However, when the numbers of users increase the random distribution becomes closer to uniform distribution because the angular distance between successive users gets very small and similar as illustrated in Table 1.

Table 1: Code Assignment Results

Number of Users	Number of Codes		Ratio
	uniform	random	

100	20	34	1.7
500	93	129	1.39
700	129	175	1.356
900	166	222	1.337
1000	185	243	1.31
2000	368	475	1.29

2. Limited Number of Spreading codes

Next we consider the case when the total number of spreading codes is limited, and users are randomly distributed. Thus, user may be blocked as discussed in section V. Fig. 6., depicts the blocking probability The total number of spreading codes is vary with a fixed number of users of 250 user distributed randomly within the cell. It is clear from the figure that adding more spreading codes shows a significant improvement on the system performance in terms of blocking probability, furthermore, it could be seen from the figure that using 62 spreading codes can guarantee that all users will be accommodated by the system.

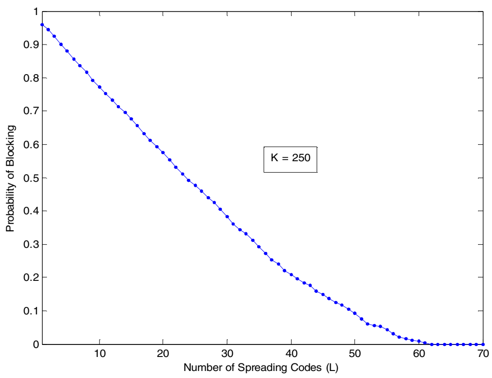

Figure 6. Probability of Blocking

Fig. 7., depicts the system performance of the combined C-SDMA using random code assignment algorithm and the proposed new code assignment algorithm. In fig. 7., 25 users were considered with 12 available spreading codes. It could be seen from the figure that the proposed algorithm enhance the system performance by about 4 dB gain compared to the random assignment algorithm at BER of 10^{-2}. Also, as the SNR value is increased, the proposed algorithm further improve the BER performance compared to the random algorithm. This is because at high SNR the MAI intensively degrade the system performance of the non-orthogonal users.

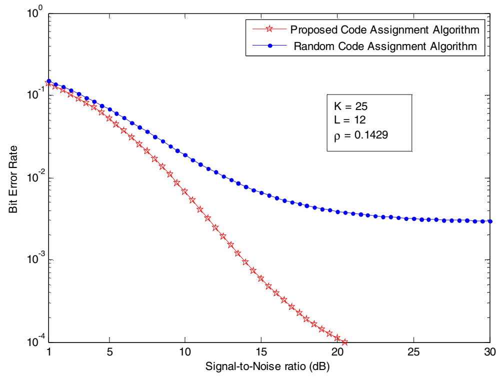

Figure 7. BER performance random and the proposed DCAA

IX. Conclusion

In this paper, the performance of dynamic code assignment has been investigated. Both limited and unlimited number of spreading codes has been considered to investigate the efficiency of the proposed algorithm under uniform and random user distributions. The results show that the reuse efficiency is optimized when the users are uniformly distributed within the cell. Moreover, for random distribution, the reuse ratio is less than that of the uniform distribution, but still able to significantly improve the system capacity. Finally, it is shown that the blocking probability is intensively decreased by adding a small number of available spreading codes.

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